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DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 159

POROSITY AND VOLUME CHANGES OF CLAY FIRE BRICKS AT FURNACE TEMPERATURES

BY

GEORGE A. LOOMIS, Assistant Ceramic Chemist

Bureau of Standards

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By George A. Loomis

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I. INTRODUCTION

1. GENERAL CONSIDERATIONS REGARDING THE TESTING OF FIRE BRICKS

The testing and classification of clay fire bricks is a subject which has received considerable attention in recent years, but which has not yet been worked out to any great degree of completeness. Failure to satisfactorily classify clay fire bricks has been due, in part, to the fact that clay refractories are used under such a variety of conditions. A fire brick which proves very satisfactory under certain conditions of use may not be able to fulfill the requirements for other uses. Fire bricks may be called upon to resist deformation under excessive, or very light, loads at high temperatures, to resist sudden changes in temperature, to with-

stand intrusion of slags or glasses, to resist abrasive action, and many other equally severe conditions. Of course, no brick could be expected to withstand all of these conditions perfectly, and it would be hardly fair to condemn the use of a brick for all purposes because of failure to withstand any one of these conditions. However, it is generally conceded that refractoriness is a primary requisite of a fire brick for general use; and other properties, such as ability to resist abrasion or the penetration of slags, may be said to be of secondary importance. Therefore, the question of the satisfactory evaluation of refractoriness has proved the main problem in the testing and classification of clay fire bricks.

2. MEASUREMENT OF REFRACTORINESS

In working out a satisfactory classification of fire bricks, based on refractoriness several tests for the measurement of this property have been put into more or less general use. Of these the three which have been used the most are, first, the chemical analysis, which gives a theoretical indication of refractoriness; second, the direct determination of the so-called softening point; and third, the determination by an actual load test of the ability of a fire brick to resist deformation under loads at high temperatures. These tests will be described more in detail later. Another test as a measurement of refractoriness, but which has not been used very extensively in the case of fire bricks, is the determination of porosity and volume changes on heating the bricks to different temperatures. A decrease in porosity and volume indicates the progress toward vitrification, and when these changes are plotted in the form of curves the slope of the curves shows the rate of vitrification. Overfiring is then indicated by an increase in porosity and by an increase in volume as the vesicular structure accompanying overfiring is developed. A classification of fire clays, based on porosity changes, was first suggested by Purdy,[1] who set the limits for the different grades of refractories, as shown by the curves in Fig. 1. The idea of measuring the refractoriness of a fire brick by its changes in porosity and volume is evidently a sound one.

3. TEMPERATURE-POROSITY CHANGES AS AN INDICATION OF LOAD-CARRYING ABILITY

The value of the determination of porosity and volume changes is all the more evident when it is realized that the degree of vitrification, as shown by the changes in porosity, also represents the

[1] Purdy, R. C., Bull. No. 9, Ill. Geol. Sur.

amount of softening which must necessarily take place in the process of vitrification. Marked softening of the mass of the brick means decreased resistance to deformation. In other words, the changes in porosity may be said to bear some relation to the resistance to deformation of a brick under load at high temperatures.

4. OBJECT OF PRESENT INVESTIGATION

From the above considerations it is evident that the determination of the porosity and volume changes is very valuable in the study of the fundamental properties of clay fire bricks, and it is only by a better knowledge of the fundamental properties that a

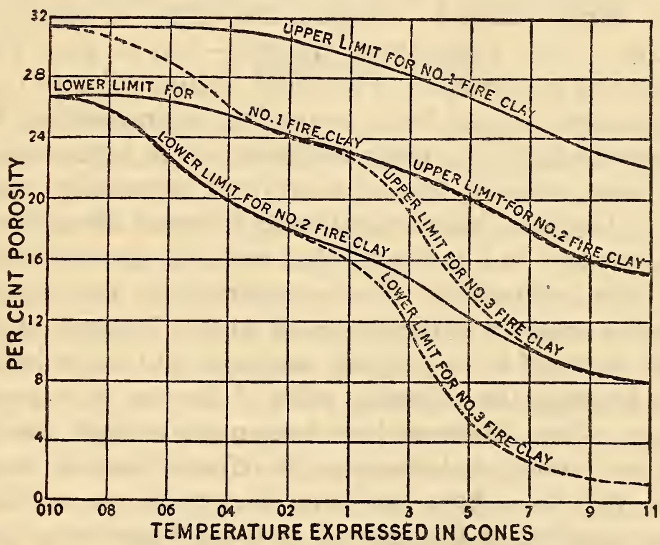

FIG. 1.—*Diagram showing Purdy's classification of fire clays*

completely satisfactory classification of fire bricks can be worked out. Therefore, the present investigation was undertaken in order to study the fundamental properties of clay fire bricks by a comparison of their changes in porosity and volume on heating to different temperatures with the results of a specific load test and with the so-called softening points.

Preliminary work on this investigation was first undertaken under the direction of G. H. Brown when connected with this Bureau. It was afterwards decided to take up the investigation on a larger scale, with the cooperation of the Refractories Manufacturers' Association, which kindly furnished samples of a greater number of brands of fire bricks for the tests, and likewise in the interest of the American Gas Institute.

II. DESCRIPTION OF FIRE-BRICK TESTS ALREADY USED

Before taking up the details of the present investigation it is well to describe and discuss briefly the most noteworthy tests which are being used in determining the value of clay fire bricks, including the tests which have been mentioned already.

1. CHEMICAL ANALYSIS

The chemical analysis has been used to quite an extent in the study of the fundamental properties of fire bricks and is of considerable value, not only in this regard but also in explaining the causes of failure in use. The chemical analysis serves as an indication of refractoriness by showing the degree of purity of the clay. Clay of the purest type possible—that is, pure kaolin—has a softening temperature, or so-called melting point, of 1740° C.[2] This purest form of clay has a composition corresponding to that of the mineral kaolinite, being composed of 46.3 per cent silica, 39.8 per cent alumina, and 13.9 per cent chemically combined water. In burning, this chemical water is driven off and the composition becomes 53.8 per cent silica and 46.2 per cent alumina. Clay of this composition is of comparatively rare occurence, owing to the presence in most cases of quartz, feldspar, magnesia, lime, and iron oxide, in varying amounts, and these behave as fluxes in lowering the softening point of the clay to a greater or less extent. Some attempts have been made to apply the chemical analysis directly as a measure of refractoriness by means of formulas, but these have not been in any degree satisfactory. The determination of the amount of these fluxes by a chemical analysis, may, however, be considered as an aid in determining the refractoriness of the clay, as well as serving in some measure to explain the failures of clay fire bricks in use.

A classification of fire bricks based on the chemical analysis has been proposed [3] which fixes the limit for the permissible amount of fluxes for No. 1 grade bricks. According to this classification, the total amount of fluxes must not exceed 0.22 molecular equivalents. This expression for the amount of fluxes is a part of the empirical formula commonly used in the study of ceramic bodies. This is calculated from the chemical analysis by dividing the respective percentages by the molecular weights of the oxides and then dividing each value obtained by the value for

[2] B. S. Technologic Paper No. 10.

[3] B. S. Technologic Paper No. 7.

the alumina. The vaiues for tne various fluxes are then summed up, and the formula obtained is of the type x, SiO_2. 1 $Al_2.O_3.yRO$. In this formula, determined for fire bricks, the RO equivalent must not exceed 0.22 for the No. 1 fire bricks, according to the suggested classification. In the case of the siliceous clay brick (say 65 per cent or more of silica) the permissible amount of fluxes is considerably less since the fluxes are more effective upon siliceous material. It is quite evident, then, that the chemical analysis is of some value in studying the causes of failure of refractories. However, there are physical tests which require less time to perform than the chemical analysis, and yet indicate much more satisfactorily the value of a fire brick in a practical manner.

2. SOFTENING POINT

The determination of the so-called softening point is one of the most widely used tests for fire bricks and is generally considered a reliable indication of the refractoriness of the material. In determining the softening point, small tetrahedra of the size of the well known Orton standard higher pyrometric cones, are molded from a portion of the brick ground to pass about an 80-mesh screen, and mixed with a gum-tragacanth solution to serve as a temporary bond. These are then set in a suitable plaque of refractory clay material beside a series of standard pyrometric cones and heated in a carbon-resistance electric furnace, or a small pot furnace heated with a gas-blast burner of the Fletcher type. The softening point is determined by the point at which the test cone deforms to the extent that the tip is on a level with the base or the cone has swelled excessively. Results are expressed in terms of the standard cone which has deformed to the same extent. Temperatures are not usually considered since it is a well-known fact that the bending of the standard cones is affected by the rate of heating. However, very good comparative results are obtained by limiting the time of firing on such a test to an hour and a half or two hours.

In classifying fire bricks according to the softening point cone 30 is usually considered the lowest value for No. 1 grade, cones 30 to 28 for No. 2, and cones 28 to 26 for No. 3 grade. This classification is, no doubt, a proper one, but, at the same time, it quite often proves misleading, in so far that the bricks with a higher softening point—cone 32 or above—sometimes fail to withstand practical conditions of load and temperature while

siliceous bricks, low in fluxes, with a softening point as low as cone 29, generally stand up well under heavy loads at fairly high temperatures. This is explained by the fact that siliceous bricks remain quite rigid to within about 100° C of their softening point, while the brick lower in silica softens through a longer range, Then, too, the softening-point determination is misleading in the case of bricks made from a coarse mixture of very refractory nonplastic clay (flint clay) with an inferior bond clay. The comparatively fine grinding necessary to molding the cones brings about a more intimate mixture of the material, so that the refractoriness is raised. This objectionable feature of the softening-point test is sometimes overcome by using a chip of the original brick cut on a carborundum wheel to the form and size of the standard cones. This, however, is often a difficult task and is practically impossible in the case of a very coarse, friable material, to say nothing of the variation in the results from not obtaining an average sample from so small a specimen.

3. LOAD TEST

What is known as the standardized load test was first used by this Bureau in an investigation of clay refractories. This test has proved the most practical and surest means of determining the behavior of fire bricks in use under high loads and temperatures. The test is generally performed upon a brick of standard size and shape placed on end in a specially designed furnace of about 20 by 20 by 20 inches, internal dimensions. The load is applied to the brick longitudinally through a suitable opening in the top of the kiln by means of a highly refractory column, on which rests a horizontal beam. On the furnace used by the Bureau this beam rests upon a knife-edge on the column and acts as a lever fastened and adjustable at one end to keep it level, and the load is applied at the other end. On a later type of load-test furnace the beam is balanced by applying an equal load on both ends, and no knife-edge is used. The firing, in the case of the Bureau's furnace, is done by means of eight Fletcher gas-blast burners, two on each side and four in front. In conducting this test the temperature is raised at a specified rate to the maximum temperature, which is held for one and a half hours. It has been found that 1350° C is the most suitable maximum temperature in testing first-grade fire bricks. A load of 40 pounds per square inch has been used, although this is rather severe, and one of 25 pounds per square inch is believed a fairer test for No. 1 bricks.

Although there are no standard specifications for clay fire bricks as yet, one-half inch contraction in length of a 9-inch brick is considered the permissible limit for a No. 1 refractory with a load of 40 pounds per square inch at 1350° C. All clay fire bricks which have not deformed more than one-half inch in such a test have proved very satisfactory in use under average loads at average furnace temperatures. Hence there seems to be no doubt whatever of the practical value of the load test. It may be a little too severe in rejecting bricks which might prove satisfactory in use, but this fault is easily remedied by decreasing the load applied.

4. COLD CRUSHING TEST

This test is a rather valuable one in eliminating unsatisfactory bricks from consideration for use under loads at high temperatures without taking time for the load test at furnace temperatures. Obviously a refractory possesses but a small part of its cold crushing strength at a temperature of 1350° C, and if a brick has a low crushing strength when cold it is almost certain to fail in a load test at 1350° C. It has been found that a cold crushing strength of 1000 pounds per square inch, when the brick is tested on end, is about the lowest permissible value in this regard.

5. BALL TEST

A special form of load test called the ball test has been put into use by Dr. J. S. Unger and C. E. Nesbitt, of the Carnegie Steel Co.[4] This test was devised in attempting to find a substitute for the regular load test, which could be performed on a larger number of bricks in a short time. It is claimed that results compare favorably with those of the regular load test. The test is made by heating bricks to 1350° C for one hour in a furnace, drawing them out quickly and laying them on their side under a long lever in such a manner that a 2-inch iron ball placed on the brick under the lever is depressed into the face as increasing pressure is applied to the lever. A certain load is applied which is gradually brought up to a maximum in about five minutes. The depression made by the ball is measured in inches. The proper load to give a depression comparable to the contraction in a regular load test was determined by experiment. There is no doubt that such a test can be made on a number of bricks in much less time than is required by the regular load test. How-

[4] C. E. Nesbitt and M. L. Bell, Proc. Am. Soc. for Testing Materials, **19**, p. 349; 1916.

ever, there is some objection to it as a regular test for fire bricks on the ground that cooling takes place sufficiently during the test to influence the results. Then, too, the portion of the brick receiving the pressure is a small part of the whole brick, and the results are apt to be affected by small local defects in the structure of the brick.

The special tests of fire bricks, such as the determination of the resistance to slagging action, the resistance to impact and abrasion, and the test of ability to withstand sudden temperature changes, have little or no connection with the present investigation and need not be described here. [5]

III. METHOD OF STUDY OF POROSITY AND VOLUME CHANGES IN CONNECTION WITH LOAD TESTS AND SOFTENING POINTS

1. DETERMINATION OF POROSITY AND VOLUME CHANGES

Taking up the details of the present investigation, the porosity and volume changes of the fire bricks, for comparison with the results of load tests and softening points were determined in the following manner: Specimens of each brand of fire brick were cut with a broad chisel into briquets, approximately 2½ by 1¼ by 1¼ inches in size, squared up somewhat on a grinding wheel, and suitably marked with cobalt paint (made by mixing powdered cobalt oxide, 1 part, and kaolin, 3 parts, in water). Six briquets were cut for each brand. A neater method of cutting the specimens would have been to use a carborundum cutting wheel. However, the method used was quicker and equally as good except for the appearance of the specimens.

The initial porosity was then determined on two of these small specimens from each brand by first weighing the specimens to 0.10 gm after drying at 110° C and then determining the wet weight and the suspended weight after saturating in boiling water under a partial vacuum, represented by a 24-inch mercury column, for four hours. The per cent porosity was then determined from the Purdy formula:

$$\frac{\text{Wet weight} - \text{dry weight}}{\text{Wet weight} - \text{suspended weight}} \times 100 = \text{per cent porosity}.$$

The volume of the six briquets of each brand was then accurately determined in a volumenometer of the Seger type after

[5] For description of these special tests see Nesbitt and Bell, Practical Methods for Testing Refractory Fire Bricks, Proc. of Am. Soc. for Testing Materials, 16, p. 349; Brown, Method of Testing Corrosive Action of Slags, Trans. Am. Ceram. Soc., 18, p. 277.

soaking the specimens in oil. Duplicate determinations of each volume were made to obtain a check within 0.2 cc.

The six briquets of each brand were then set for reburning in a muffle in a test kiln in such a manner that a specimen for each brand could be drawn at regular intervals in the process of firing. Space was left between each set of draws and between individual piles to allow the equal heating of all briquets. A set of pyrometric cones and a thermocouple in a porcelain protecting tube were placed inside the muffle beside the briquets. With this arrangement the size of the muffle permitted the burning of 84 specimens or 14 brands at one time.

In burning the briquets, the temperature was brought rapidly up to 250–300° C and held for three or four hours in order to vaporize the oil in the briquets without igniting. Overnight the temperature was brought up to 800° C, this being the highest temperature that could be attained on this kiln without compressed air, which was not usually available at night. From 800° C the temperature was raised rapidly to 1200° C. The firing was then conducted at the rate of 30° C per hour from 1200 to 1500° C. The draws were made at 50° C intervals between 1250 and 1500° C and were cooled slowly by covering with hot sand in a suitable container.

The deformation of the standard cones as observed during the firing of the briquets was as follows:

Cone 13 down at 1350° C.
Cone 15 down at 1450° C.
Cone 17 down at 1500° C.
Cone 18 half down at 1500° C.

As usual, the cones were considered down when the tip was on a level with the base. It may be well to note here that cones, when used in a burn of this kind, are retarded slightly owing to the cooling unavoidably given them in making draws.

After the burning of the briquets the porosity of each was determined by the same method used in determining the initial porosities. It may be said in regard to the method of soaking the specimens that placing them in boiling water under a partial vacuum for four hours gave more consistent results than the usual method of simply boiling in water. It was found that results could be checked exactly on the same specimen by the vacuum method, whereas results by the boiling test alone were found to be sometimes as much as three points lower than by the vacuum method.

The final volumes of the briquets were determined in the volumenometer in the same manner as the initial volumes, checking

duplicate determinations on the same briquets to 0.2 cc. The volume change was computed in terms of the initial volume. The volume changes and porosities at the different temperatures were plotted in the form of curves for each brand of brick.

2. METHOD OF MAKING LOAD TEST

The regular load test was made on a full-sized specimen of each brand (standard-size bricks used), employing for an hour and a half a load of 40 pounds per square inch at a temperature of 1350° C The load of 40 pounds per square inch was considered best for testing first-grade fire bricks at the time the tests were made.

The kiln used for the load test was the one which has already been described.[6] Special care was used during these tests to keep the beam level at all times to prevent eccentric loading on the specimen. The usual rate of firing up to 1350° C was followed. It is given in Table 1.

TABLE 1.—Schedule of Firing in Load Test

Time		Tempera-ture, °C	Time		Tempera-ture, °C	Time		Tempera-ture, °C
Hours	Minutes		Hours	Minutes		Hours	Minutes	
	15	200	1	45	960	3	15	1240
	30	370	2	....	1020	3	30	1270
	45	520	2	15	1070	3	45	1300
1	....	670	2	30	1120	4	....	1320
1	15	800	2	45	1160	4	15	1340
1	30	880	3	....	1200	4	30	[a]1350

[a] 1350° C held for an hour and a half.

The thermocouple used in measuring the temperature was placed within one-half inch of the bricks in a porcelain protecting tube. Cones were also placed close to the bricks as a check on the firing, although couples and instruments used in this test and for the porosity determinations were from time to time calibrated against standards to insure accuracy in measuring temperatures.

When the investigation was first started, the plan was to make duplicate determinations of the load test and to take the average result for comparison with the results of the porosity and volume-change determinations. However, the variation in initial porosity on different specimens of the same brand of bricks is sometimes quite considerable, due in most cases to a difference in burning in manufacture. It was therefore, decided to determine the initial

[6] B. S. Technologic Paper No. 7.

porosity on several of the full-sized bricks of each brand in the same manner as was done with the briquets and to use the brick for the load test which was found to have the nearest porosity corresponding to that of the briquets used in the other test. By so doing, it seemed that a good comparison of results of the load test with those of the porosity and volume-change determination could be made without making duplicate determinations of the load test on each brand. Under the circumstances, it did not seem worth while to take the time for more than one load test on each brand, considering the large number of brands tested.

3. METHOD OF DETERMINING SOFTENING POINTS

The softening-point determinations were made by grinding up portions of the bricks to pass a 60-mesh screen and molding with gum tragacanth into cones as nearly as possible the exact size of the Orton higher-pyrometric cones. These were set in a plaque of suitable refractory clay material with a series of pyrometric cones in the usual manner of determining softening points and fired in a small pot furnace, using a Fletcher blast burner with natural gas and compressed air. The time of firing on each test was limited to an hour and a half to two hours. The softening point was determined by the point at which the cones bent in the prescribed manner and the result expressed in terms of the corresponding standard cone. Duplicate determinations of the softening point were made on two bricks of each brand. Practically all of the results agreed within one-fourth of a cone and in no case did duplicate determinations on two bricks differ more than one-half cone.

IV. RESULTS

The results of the determinations of the changes in porosity and volume, the load tests, and the softening points are given in Tables 2 and 3. The names of the brands are not given for obvious reasons, although the districts where they are made are indicated. The method of manufacture indicated in Table 2, was learned through information furnished by the makers. A general idea of the nature of the clays used, as explained by the manufacturer, is also indicated. Such information was not available in some cases, The bricks indicated as being handmade were hand molded and hand re-pressed; the stiff-mud bricks were made by a steam press or auger machine and power re-pressed, in accordance with common practice by the two methods. A great majority of the bricks in-

dicated as being made from a mixture of clays were made from the hard, highly refractory, nonplastic clays known as flint clays, bonded with a less-refractory, plastic clay, this being a common practice in the manufacture of clay fire bricks, especially in Pennsylvania.

The porosities and volume changes at the temperatures shown in the tables were taken from curves plotted accurately according to the actual temperatures at which the draws were made. The results of the load tests, given in Table 3, are expressed both in inches and in per cent of contraction figured upon the original length.

TABLE 2.—Results of Tests of Fire Bricks Investigated

[Porosity and volume changes up to 1400° C. Other results are given in Table 3]

Laboratory No. of brand	District where made	Process of manufacture	Per cent initial porosity of briquets	Per cent initial porosity of brick used in load test	Per cent porosity at 1300° C	Per cent volume change at 1300° C	Per cent porosity at 1350° C	Per cent volume change at 1350° C	Per cent porosity at 1400° C	Per cent volume change at 1400° C
1	Pennsylvania	Stiff mud, using mixture of clays	14.24	(a)	13.10	0.00	12.25	+0.10	10.50	+1.00
2	do	Soft-mud machine, using mixture of some flint clay with plastic	23.65	(a)	17.20	−1.50	16.50	+ .75	16.95	+6.65
3	do	Soft-mud machine, using one clay	22.80	(a)	16.35	−2.35	14.40	− .70	14.60	+5.50
4	do	Handmade, using mixture of clays	23.15	(a)	22.90	− .30	22.50	+ .10	21.95	.00
5	do	Handmade, using mixture of flint clay with plastic	21.28	(a)	20.00	.00	19.15	+ .30	17.55	+1.30
6	Maryland	Stiff mud, using mixture of flint clay with plastic	24.46	(a)	....	....	20.50	−3.10	18.00	−2.95
7	do	Handmade, using mixture of flint clay with plastic	26.05	(a)	13.80	−7.80	13.25	−6.30	19.25	+6.75
8	do	Stiff mud, using mixture of flint clay with plastic	22.95	(a)	11.65	−7.00	12.25	−5.00	16.45	+2.50
9	do	Handmade, using mixture of flint clay with plastic	26.82	(a)	25.25	.00	24.25	.00	23.15	− .15
10	do	do	30.00	(a)	16.75	−9.15	16.10	−7.15	16.10	−3.25
11	Missouri	Stiff mud	18.03	(a)	17.45	.00	16.15	− .40	15.00	− .35
12	do	do	19.50	(a)	18.40	− .25	16.50	−1.00	14.10	−2.60
13	do	do	14.15	(a)	14.00	− .05	13.50	− .10	13.20	−1.00
14	do	Dry pressed	16.33	(a)	16.15	.00	15.70	.00	13.75	− .90
15	Pennsylvania	Soft-mud machine, using one clay	16.83	(a)	15.80	.00	15.50	.00	15.00	.00
16	do	Soft-mud machine, using mixture of clays	21.67	(a)	20.20	− .45	19.00	−1.00	17.10	− .60
17	Kentucky	Stiff mud, using mixture of plastic and hard-soft clays	12.40	(a)	10.90	.00	9.40	− .35	8.50	+ .25
18	Colorado	Dry press, using two plastic clays	25.32	(a)	25.15	− .20	25.20	.00	25.60	+ .30
19	do	Stiff mud, using mixture of plastic and flint clay	26.65	(a)	26.50	.00	26.25	− .25	25.90	− .40
20	do	Handmade, using mixture of clays	25.60	(a)	25.30	− .25	25.50	− .40	25.65	− .40
21	do	do	24.22	(a)	22.90	− .15	23.40	− .30	24.15	− .40
22	do	Stiff mud, using mixture of clays	23.07	(a)	22.70	− .25	22.35	− .35	22.40	− .75
23	do	Stiff mud, using mixture	19.08	(a)	18.75	+ .20	18.05	+ .30	17.80	− .10

[a] Not determined.

TABLE 2.—Results of Tests of Fire Bricks Investigated—Continued

[Porosity and volume changes up to 1400° C. Other results are given in Table 3]

Laboratory No. of brand	District where made	Process of manufacture	Per cent initial porosity of briquets	Per cent initial porosity of brick used in load test	Per cent porosity at 1300° C	Per cent volume change at 1300° C	Per cent porosity at 1350° C	Per cent volume change at 1350° C	Per cent porosity at 1400° C	Per cent volume change at 1400° C
24	Pennsylvania	Dry pressed, using one clay	19.54	16.20	18.90	+ 0.25	19.15	+0.10	18.50	+ 0.25
25	do	Handmade, mixture of plastic and flint clay	19.95	19.22	20.15	.00	19.25	− .30	18.75	− .45
26	Maryland	Stiff mud, using single clay	13.44	14.90	10.60	− .75	8.60	− .30	7.00	+ .10
27	do	Handmade, using mixture of clays	24.55	....	20.95	− 1.15	21.00	+1.00	21.00	+ 3.20
28	do	do	27.86	25.85	24.95	− 1.60	22.25	−2.85	20.50	− .70
29	do	Stiff mud, using mixture of clays	21.10	....	18.67	− 1.40	14.65	−3.65	13.30	− 3.15
30	Pennsylvania	Handmade, using mixture of clays	20.78	21.30	19.30	+ .26	16.25	+ .40	15.85	+ 1.60
31	do	do	23.63	22.00	22.25	− .25	19.85	− .75	18.60	+ .25
32	do	Handmade, using mixture of plastic and flint clays	23.33	24.90	21.65	+ .15	21.90	+1.60	19.45	+ 3.30
33	Ohio	Stiff mud, using single clay	17.95	15.98	14.95	− 1.65	10.80	−4.15	9.00	− 3.95
34	do	Handmade, using mixture of plastic and flint clays	25.98	26.40	19.75	− 3.55	19.70	−3.08	18.35	− 3.70
35	do	Handmade, using mixture of hard-soft and plastic clays	22.13	23.10	18.90	− .15	16.65	−1.25	14.70	− .74
36	do	Dry pressed, using one clay	21.23	23.60	17.95	− .85	18.05	+ .90	15.45	+ 2.05
37	do	Handmade, using one clay	26.77	25.20	10.60	−12.90	21.15	+1.60	27.65	+12.95
38	do	Handmade, using mixture of plastic and flint clays	39.36	30.20	27.40	− 2.85	25.65	−3.95	23.55	− 5.45
39	do	do	30.10	28.00	28.70	.00	28.30	− .40	26.45	− 3.05
40	Pennsylvania	Handmade, using mixture of clays	23.98	20.05	16.50	+ .50	15.00	+1.55	14.40	+ 3.50
41	do	do	24.07	23.05	21.30	− 1.50	20.50	−1.05	19.00	− .35
42	do	do	21.66	23.90	21.50	− .65	20.50	−1.10	17.75	+ .30
43	do	do	18.57	23.50	17.80	− .35	16.50	− .55	14.55	+ .85
44	do	Soft-mud machine, using mixture of flint and plastic clays	20.90	23.35	22.40	+ .45	20.50	+ .40	19.25	+ .25
45	Illinois	Stiff mud	29.55	30.05	28.40	− .65	26.70	−1.75	24.10	− 4.25
46	do	do	22.15	22.00	20.85	+ .30	19.80	.00	18.45	− .50
47	do	do	24.58	25.45	21.80	− .80	20.00	−1.55	17.50	− 2.25
48	Ohio	Stiff mud, using mixture of clays	16.65	15.83	16.25	+ .55	13.75	+ .80	11.40	− .15

49	Pennsylvania	do	15.35	16.70	9.15	+ .60	9.30	+3.50	8.05	+ 6.50
50	do	do	18.15	16.80	18.70	.00	18.40	+ .45	18.10	+ .35
51	do	Handmade, using mixture of clays	19.44	22.75	19.75	+ .25	19.65	+ .10	19.10	− .15
52	West Virginia	Handmade, using mixture of plastic and flint clays	23.37	28.70	23.20	+ .65	22.20	+ .10	19.60	+ .20
53	do	Stiff mud, using mixture of plastic and flint clays	21.15	20.05	18.80	+ 5.20	18.45	+8.65	16.10	+12.00
54	Ohio	Handmade, using mixture of plastic and flint clays	25.97	27.10	25.20	− .65	21.55	−2.30	19.50	− 3.50
55	Pennsylvania	do	22.12	22.75	21.30	.00	21.00	− .10	19.85	+ .15
56	Missouri	Apparently stiff mud	20.25	19.45	19.60	− .35	19.25	− .30	17.65	− .95
57	Kentucky	Stiff mud, using mixture of clays	21.25	22.55	20.65	+ .35	20.50	.00	19.05	− .35
58	Missouri	Apparently stiff mud	18.69	23.40	17.75	− .40	16.00	−1.20	14.00	− 1.55
59	do	Dry pressed	24.58	18.28	23.80	+ .25	24.00	+ .55	21.35	+ .55
60	Kentucky	Handmade, using mixture of plastic and hard-soft clays	20.27	19.55	19.30	− .05	17.10	− .65	15.35	− .10
61	do	do	20.24	21.80	16.00	− 1.15	14.25	−1.50	11.60	− 1.40

TABLE 3.—Results of Tests on Fire Bricks Investigated

[Porosity and volume changes below 1425° C are given in Table 2]

Laboratory No. of brand	Per cent porosity at 1425° C	Per cent volume change at 1425° C	Per cent porosity at 1450° C	Per cent volume change at 1450° C	Per cent porosity at 1500° C	Per cent volume change at 1500° C	Points decrease in porosity from initial to 1425° C	Points decrease in porosity from initial to 1450° C	Result of load test: deformation in inches and per cent	Softening-point cone
1	9.50	+ 1.75	9.00	+ 2.65	7.90	+ 4.10	4.74	5.24	0.40 inch=4.48 per cent	32
2	17.60	+10.50	19.20	+15.00	20.20	+22.30	6.05	4.45	1.72 inches as temperature reached 1350° C	20
3	15.75	+ 9.75	18.90	+14.25	22.75	+24.80	7.05	3.90	1.77 inches=20.1 per cent at 1335° C	20
4	21.40	.00	20.65	+ .90	19.60	+ 1.60	1.75	2.50	0.33 inch=3.70 per cent	33
5	16.75	+ 2.00	16.95	+ 2.75	15.60	+ 4.40	4.53	4.33	Bond gave way after 15 minutes at 1350° C	31¼
6	16.65	− 2.80	15.75	− 2.40	13.30	− 1.55	7.81	8.71	1.05 inches=12.1 per cent	31¼
7	23.00	+14.40	23.40	+15.50	....	+17.50	3.05	2.65	1.16 inches=13 per cent at 1320° C	27½
8	19.50	+ 7.75	22.95	+13.75	....	+21.75	3.45	.00	1.45 inches=16.5 per cent after 25 minutes at 1350° C	27½
9	22.50	.00	21.20	+ 1.75	19.75	+ 5.40	4.32	5.62	Bond gave way at 1345° C	31¼
10	16.10	− :75	15.00	+ 1.40	13.40	+ 4.90	13.90	15.00	1.82 inches=20.1 per cent at 1340° C	28
11	14.30	− .25	13.25	− .50	11.35	− .50	3.73	4.78	0.28 inch=3.23 per cent	29¼
12	12.80	− 3.40	11.80	− 3.00	9.80	− .95	6.70	7.70	0.49 inch=5.47 per cent	31
13	12.65	− 1.60	10.00	− 2.50	7.00	− 3.50	1.50	4.15	0.09 inch=1.06 per cent	31¾
14	12.30	− 1.60	11.00	− 1.90	7.85	− 1.75	4.03	5.33	0.44 inch=5.03 per cent	32
15	14.75	.00	14.65	+ .50	14.00	+ 1.10	2.08	2.18	0.27 inch=3.17 per cent	31¾
16	16.10	− .25	15.40	.00	14.90	+ 1.90	5.57	6.27	0.30 inch=3.5 per cent	32
17	8.15	+ .75	7.60	+ 1.50	6.50	+ 4.00	4.25	4.80	0.40 inch=4.6 per cent	31
18	25.85	+ .40	25.85	+ .60	24.75	+ .25	+(.53)	+(.53)	0.01 inch=0.11 per cent	29¼
19	25.60	− .50	25.05	− .90	21.60	− 3.40	1.05	1.60	0.21 inch=2.37 per cent	31
20	25.60	− .60	25.00	− .60	23.00	− 2.50	.00	.60	0.14 inch=1.62 per cent	32
21	24.30	− .50	23.40	− .55	19.80	− 2.30	+(.08)	.82	0.28 inch=3.3 per cent	32
22	22.30	− 1.25	21.35	− 2.25	15.50	− 5.85	.77	1.72	0.23 inch=2.56 per cent	31
23	17.40	− .50	15.35	− 1.25	10.75	− 2.00	1.68	3.73	0.10 inch=1.11 per cent	28
24	17.80	+ .30	17.05	+ .15	15.00	− 2 75	1 74	2.49	0.57 inch=6.46 per cent	31¼
25	18.40	− .40	17.50	− .50	16.50	− .90	1.55	2.45	0.30 inch=3.45 per cent	32½
26	6.70	+ 1.20	7.50	+ 5.25	7.50	+11.50	6.74	5.94	1.10 inches=12.6 per cent	29

27	20.20	+ 5.60	19.50	+ 8.00	21.25	+13.15	4.35	5.05	0.79 inch=9.24 per cent	32
28	21.00	− .40	21.50	− .30	19.95	+ 3.05	6.86	6.36	1.17 inches after 45 minutes at 1350° C	31¾
29	12.35	− 2.50	11.40	− 2.00	10.75	+ 1.90	8.75	9.70	0.67 inch=7.54 per cent	30
30	20.25	+ 8.00	24.60	+14.80	23.90	+14.65	.53	+(3.82)	2.2 inches at 1315° C	20
31	18.00	+ .80	17.50	+ 1.25	15.15	+ 4.55	5.63	6.13	Bond gave way after 30 minutes at 1350° C	29¼
32	18.80	+ 3.10	18.30	+ 2.80	17.90	+ 5.00	4.53	5.03	Bond gave way at 1330° C	30¾
33	8.25	− 2.55	7.80	− 1.35	13.15	+ 4.30	9.70	10.15	2.25 inches after 30 minutes at 1350° C	31¼
34	16.40	− 2.30	14.50	− 0.90	14.15	− 2.05	9.58	11.48	Bond gave way at 1345° C. after considerable settle	28¾
35	14.25	+ 1.00	13.70	+ 2.75	14.85	+ 5.15	7.88	8.43	1.49 inches after 15 minutes at 1350° C	28½
36	13.10	....	10.75	....	12.90	....	8.13	10.48	2.07 inches at 1345° C	27
37	26.77	+18.30	32.25	+23.60	29.70	....	3.23	+(5.48)	2.07 inches at 1295° C	26½
38	21.90	− 5.80	20.10	− 6.30	18.00	− 8.75	8.46	10.26	0.90 inch=10.4 per cent	30¼
39	25.30	− 3.40	24.40	− 3.95	22.65	− 5.45	4.80	5.70	0.89 inch =10.4 per cent	30¼
40	14.40	+ 4.65	14.50	+ 5.50	14.95	+ 8.25	9.58	9.48	1.27 inches after 30 minutes at 1350° C	31¾
41	18.30	+ .20	18.30	+ 1.25	18.55	+ 3.60	5.77	5.77	0.75 inch=8.53 per cent	33½
42	16.30	+ 1.30	16.20	+ 2.50	16.00	+ 6.00	5.36	5.46	0.73 inch=8.31 per cent	31¾
43	13.70	+ 2.00	14.00	+ 3.50	13.75	+ 6.85	4.87	4.57	Brick bent into S shape after 10 minutes at 1350° C	29¾
44	18.90	+ .20	19.00	+ 1.00	18.60	+ 1.65	2.00	1.90	0.42 inch=4.78 per cent	33¼
45	22.55	− 5.70	21.00	− 7.00	16.90	− 9.40	7.00	8.55	0.48 inch=5.33 per cent	31
46	17.65	− .80	17.10	− 1.00	14.15	− 2.90	4.50	5.05	0.40 inch=4.47 per cent	29
47	16.20	− 2.50	15.50	− 3.40	12.60	− 5.05	8.38	9.08	0.78 inch=8.76 per cent	30
48	10.50	− .60	10.30	.00	9.50	+ 3.75	6.15	6.35	0.41 inch=4.67 per cent	31¼
49	7.35	+ 8.00	7.75	+10.10	8.70	+15.00	8.00	7.60	0.83 inch=9.37 per cent	31¼
50	17.90	+ .25	17.75	+ .25	17.00	+ .70	.25	.40	0.23 inch=2.6 per cent	32½
51	18.60	− .50	17.76	− 1.00	15.35	− 5.10	.84	1.68	0.82 inch=9.3 per cent	32
52	18.30	+ .30	18.50	+ 1.00	17.25	+ 2.35	5.07	4.87	0.78 inch=8.9 per cent	32
53	14.65	+13.60	15.00	+15.85	15.50	+20.70	6.30	6.15	2.05 inches at 1335° C. bond gave way	29¼
54	19.00	− 3.80	18.60	− 4.00	17.25	− 4.20	6.97	7.37	0.45 inch=5.09 per cent	32
55	19.10	+ .40	18.20	+ .75	16.10	+ 1.25	3.02	3.92	0.50 inch=5.63 per cent	31¼
56	16.60	− 1.50	16.10	− 2.25	13.30	− 4.10	3.65	4.15	0.18 inch=2.06 per cent	32¼
57	18.00	− .55	16.75	− .80	14.35	− 2.15	3.25	4.50	0.16 inch=1.77 per cent	32¼
58	13.00	− 1.50	11.75	− .75	10.05	− 1.00	5.69	6.94	0.42 inch=4.7 per cent	29¼
59	19.20	+ .60	16.75	+ .60	14.20	+ 3.10	5.28	7.83	0.52 inch=5.8 per cent	29
60	14.75	+ .40	14.50	+ 1.00	14.10	+ 6.60	5.52	5.77	0.31 inch=3.5 per cent	31¼
61	10.50	− 1.15	11.00	− .50	10.50	+ 1.35	9.74	9.24	0.72 inch=7.98 per cent	31

It is well to add before discussing the results in Tables 2 and 3 that most of the bricks tested were of a nonsiliceous character, as inferred from the information furnished by the manufacturer and from other considerations. However, some of the bricks were apparently of a siliceous nature, or their character in this respect was doubtful. Therefore, a chemical analysis was made on these few bricks to determine the silica, alumina, and iron oxide. The results are given in Table 4. It is to be regretted that, owing to the time and expense involved, it was not possible to make a complete chemical analysis of all the bricks studied in this investigation. A knowledge of the chemical analysis is always desirable in making a study of the fundamental properties of fire bricks.

TABLE 4.—Partial Chemical Analyses of Some of the Fire Bricks Investigated

Laboratory No. of brand	SiO_2	$Al_2O_3+TiO_2$	Fe_2O_3	$CaO+MgO+Na_2O+K_2O$	Total fluxes excluding TiO_2, but including iron as FeO
	Per cent	Per cent	Per cent	Per cent by difference	Per cent
11	65.93	31.31	2.96	0.00	1.33
18	80.56	18 69	1.15	.00	.52
19	69.92	28.45	2.00	.00	.90
22	67.47	30.38	1.48	.67	1.33
23	75.66	21.69	2.22	.43	1.43
24	60.07	34.88	2.22	2.83	3.83
46	73.37	24.55	2.39	.00	1.07

V. DISCUSSION OF RESULTS

A study of the data presented in Tables 2 and 3 shows some interesting relationships between the porosity and volume changes and the results of the load tests. In nearly all cases of bricks which successfully withstood the load test, showing a deformation of not more than 5.55 per cent, there is comparatively little volume change by either expansion or contraction up to 1425° C, while a considerable number of the bricks which failed in the load test show very appreciable volume changes. Similarly, the porosity decrease in the case of bricks which pass the load test is not large, while many of those which failed show considerable decrease in porosity at some point below 1425° C. In many cases overburning of bricks of poorer grade is distinctly evident from the volume and porosity changes. The sudden and more or

less pronounced expansion at the lower temperatures of firing in the case of some of the bricks (2, 3, 7, 8, etc.) is certain evidence of overburning which is confirmed by the results in the load test. An abrupt increase in porosity at the same or at a slightly higher temperature is usually noted in such cases. Invariably such bricks failed in the load test. Bricks which show either marked volume change or a considerable decrease in porosity also failed to withstand the load test.

It would seem, then, that the volume and porosity changes of clay fire bricks might serve in some measure as a criterion of their ability to withstand load at high temperatures. A careful study of the data for various burning temperatures shows some pertinent points in this connection, and the specimens will be considered in the order of the reheating temperatures.

1350°C.—Of 26 bricks which passed in the load test 23 show not more than 1 per cent volume change; 3 show more than 1 per cent. Of 35 bricks failing in the load test (showing more than 5.55 per cent deformation), 16 show not more than 1 per cent volume change and 19 more than 1 per cent.

Of 26 bricks passing the load test 25 show not more than 3 per cent porosity decrease; 1 more than 3 per cent. Of 35 failing in the load test, 13 show not over 3 per cent and 22 more than 3 per cent porosity decrease.

Combining these criteria, 33 of 61 show not more than 1 per cent volume change nor more than 3 per cent porosity decrease, 23 of these passing and 10 failing the load test. Of those showing more than 1 per cent volume change or more than 3 per cent decrease in porosity, 3 passed and 25 failed the load test.

1400°C—.Not over 2 per cent volume change was shown by 23 bricks which passed and 15 which failed in the load test. Of 23 bricks which showed over 2 per cent volume change, 3 passed and 20 failed in the load test.

Of 36 bricks showing not over 5 per cent decrease in porosity, 22 passed and 14 failed in the load test. Of 25 showing more than 5 per cent porosity decrease, 3 passed and 22 failed in the load test.

Of the bricks which showed neither a volume change greater than 2 per cent nor a porosity decrease exceeding 5 per cent, 22 passed and 10 failed in the load test.

On the basis of a volume change not exceeding 3 per cent at 1400° (amounting to about 1 per cent linear expansion or contraction), 24 passed and 19 failed in the load test. Of those exceeding 3 per cent volume change, 2 passed and 16 failed in the load test.

Excluding bricks which showed more than 3 per cent volume change or 5 per cent porosity decrease, 22 passed and 10 failed in in the load test. Of those which showed either more than 3 per cent volume change or 5 per cent porosity decrease, 4 passed and 25 failed in the load test.

1425°C.—Of 38 bricks showing not more than 2 per cent volume change, 23 passed and 15 failed the load test. Of those showing more than 2 per cent volume change, 3 passed and 20 failed the load test.

Of 34 bricks showing not over 5 per cent porosity change, 21 passed and 13 failed the load test. Of those showing more than 5 per cent porosity decrease, 6 passed and 21 failed in the load test.

Of the bricks which neither changed more than 2 per cent in volume nor 5 per cent in porosity, 20 passed and 7 failed in the load test. Of those changing more than 2 per cent in volume or 5 per cent in porosity, 6 passed and 28 failed in the load test.

It is apparent that the porosity and volume changes of clay fire bricks when burnt at some temperature between 1350 and 1425°C, offer, in some degree, a criterion of their ability to withstand the load test. The bricks passed or rejected by the suggested limitations in porosity or volume changes at the various temperatures are nearly the same in all cases. This consistency indicates that the apparent relation between these changes and the ability of bricks to withstand the load test is more than a chance one and that certain limitations in this respect might well be used as a means of rejection of a large number of bricks which would undoubtedly fail in that test. The use of either porosity or volume changes alone offers a fairly satisfactory criterion. Taken together the result is even better, since a number of bricks failing in the load test can pass one or the other specifications as regards volume or porosity change, but few of the better bricks fail to pass both.

For practical purposes a temperature should be selected which is not too high to be readily attained under ordinary conditions, but high enough so that the limitations in porosity or volume changes need not be too close to be easily measured. Probably 1400 or 1425° C would be the best temperature. From the results here obtained a temperature of 1400°C would seem most satisfactory, since the permissible limit in volume change may be made as high as 3 per cent, this practically amounting to a linear

contraction or expansion of 1 per cent. A limit of 5 per cent in porosity decrease is quite satisfactory. At this temperature also the effects of overburning in the inferior materials is likely to become sufficiently evident to be readily detected. Nearly all of the bricks which successfully withstand the load test could meet these specifications, while a majority of those that fail under load would be eliminated by excessive volume or porosity change, or both. It may be noted that in all cases bricks which showed a porosity decrease exceeding 5 per cent or a volume change exceeding 3 per cent showed a deformation in excess of 5 per cent in the load test, close to the permissible limit.

In the case of clay fire bricks an increase in volume is especially significant, as it represents evidence showing that overfiring has taken place due to a comparatively high content of fluxes. It is important, therefore, that the permissible expansion be rigidly limited to a definite value, which must be lower than that for the allowable contraction.

In the case of some of the bricks failing in the load test due to failure of the bond there were no marked changes in either volume or porosity. Generally such bricks have a very low cold crushing strength, as in the case of No. 5, which failed under a load of 365 pounds per square inch, and No. 9, which crushed at 385 pounds per square inch. The minimum allowable cold crushing strength for a No. 1 refractory is generally placed at 1000 pounds per square inch.

There is apparently little relation between the softening points and the volume and porosity changes or with the results of the load test. Some of the bricks showing high softening temperatures failed to withstand this test, while several which softened below cone 31 showed less than 5 per cent deformation. The latter were probably siliceous in character, containing more than 65 per cent SiO_2. In some cases where bricks failed the high softening point is probably due to the intimate mixture of the inferior bonding clay with the more refractory flint clay in the preparation of the test cones, the material being ground to 60-mesh size. In all cases bricks showing softening points lower than cone 28 failed completely in the load test. It may be considered, then, that cone 28 should be the minimum softening temperature of a No. 1 refractory of either siliceous or nonsiliceous character.

In Fig. 2 are shown porosity and volume change curves for six bricks of different characteristics which successfully withstood the load test. These have been selected as fairly typical of the bricks of this class. Contraction is indicated by negative volume change, expansion by positive values.

FIG. 2.—*Diagram showing relation between volume change, porosity, and temperature*

In the curves for brick No. 1 a gradual expansion, accompanied by a gradual decrease in porosity, is noted. The low initial porosity is characteristic of the stiff-mud brick. The gradual expansion would seem to indicate a siliceous character; but this seems unlikely in view of the high softening point, cone 32. The result of the load test was a deformation of 4.47 per cent.

Brick No. 13 shows gradual contraction beyond 1350° C, accompanied by an increased rate of porosity decrease above 1425° C. This is also a stiff-mud brick with low initial porosity and a softening point of cone 31¾. The deformation in the load test was slight, only 1.06 per cent.

Brick No. 18, made by dry pressing, is apparently siliceous in character, as indicated by the slight expansion on heating and the very slight porosity changes. The slight deformation in the load test, 0.11 per cent, and the softening temperature at cone 29¼, which is too low for a nonsiliceous material of this quality, also indicate a high silica content. The chemical analysis shows 80.56 per cent SiO_2 and a very low content of fluxes.

Brick No. 20, handmade from a mixture of flint and plastic clays, represents a high clay brick of excellent refractoriness. The porosity curve shows the characteristics of flint clays in the slight changes up to 1425° C. No appreciable volume of change occurs below 1450° C. The softening point is at cone 32, and the deformation in the load test was only 1.62 per cent.

Brick No. 45 showed a deformation of 5.33 per cent in the load test, close to the allowable limit. The large amounts of contraction and porosity decrease would render the quality of this brick doubtful in the light of the suggested specifications in this respect. The regularity of the porosity decrease and contraction indicates a gradual and continuous fluxing action, but with no indication of overburning. The softening point of this material was cone 31.

Brick No. 48 shows a rapid porosity decrease above 1300° C. The volume change is slight, up to 1425°, where overburning is indicated by the subsequent expansion. While the deformation in the load test (4.47 per cent) fell within the limit, the porosity change exceeds 5 per cent. The ability of this brick to withstand long-continued heat treatment at high temperatures would be somewhat doubtful, due to its overburning tendencies. The softening point was at cone 31¼.

In Fig. 3 are shown curves for some of the bricks which failed to pass the load test. Brick No. 26, with a deformation of 12.6 per cent, shows a gradual expansion above 1300° C, becoming rapid above 1400°. The increase in porosity at 1425° indicates that this is probably due to the gradual development of vesicular structure by overburning.

Brick No. 38 shows marked but gradual fluxing in its rapid decrease both in porosity and volume. It is evidently not of a siliceous character and of only fair refractoriness. The softening

point at cone 30¼ and the deformation in the load test (10.4 per cent) confirm this.

Brick No. 41 begins to overburn at 1300°, as indicated by the expansion and by the break in the porosity curve at a somewhat higher temperature. The high softening point, cone 33½, is

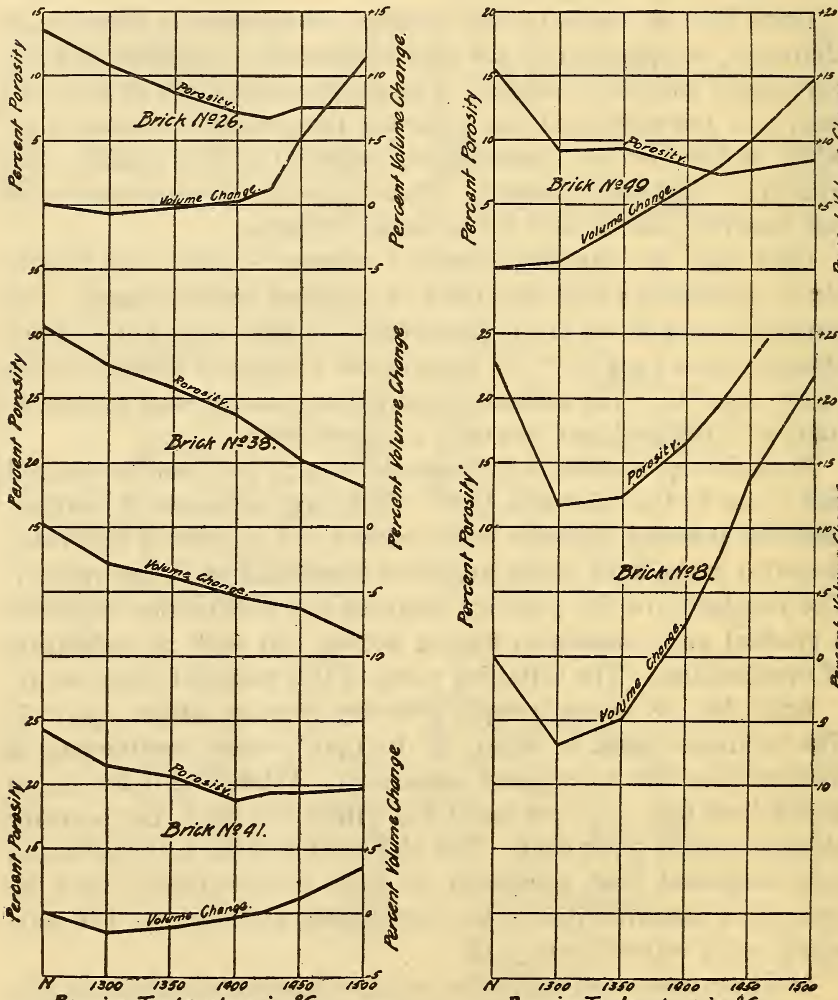

FIG. 3.—*Diagram showing relation between volume change, porosity, and temperature*

apparently the result of the fine grinding of the material in preparing the test cones. The failure to pass the load test is probably due to an inferior bond clay in the mixture.

Brick No. 49, also made from a mixture of clays, shows overburning by expansion above 1300° and the break in the porosity

curve. The softening point is at cone 31¼, and the deformation in the load test was 9.37 per cent.

Brick No. 8 is typical of a number of those which failed completely in the load test. It has a low softening point, cone 27½, and shows marked overburning above 1300° C by the rapid expansion and by the increase in porosity. The decided contraction and decrease in porosity when burnt at 1300° C indicate a low temperature of burning in manufacture.

It was also found that the average brick with an initial porosity below 21.50 per cent and which did not show evidence of overfiring to the extent referred to above had a contraction in the load test of one-half inch in a length of 9 inches, with an average decrease in percentage of porosity, up to 1425° C, of about six points. On the other hand, the average brick with an initial porosity above 21.50 per cent showed a like contraction in the load test with a change in percentage of porosity of about three points.

VI. PRACTICAL APPLICATION OF POROSITY AND VOLUME MEASUREMENTS OF CLAY FIRE BRICKS

The determination of porosity or volume changes of clay fire bricks, burnt at some temperature between 1350 and 1425° C, affords a means of separating a certain proportion of bricks which would fail in the load test. The limits of 3 per cent in volume change (or 1 per cent in linear contraction or expansion) and 5 per cent decrease in porosity at 1400° C do not eliminate all bricks which can not withstand such a test, but materially reduce the number which would require such testing. In this respect it would be of considerable advantage in comparing the quality of a large number of samples, since the porosity and volume changes may be determined readily from a single burn in a test kiln. To make standard load tests on a number of bricks requires considerable time and expense, even if several furnaces were available.

The determination of volume changes is comparatively simple when porosities are also determined, since the difference in the wet and suspended weights of the specimens affords a measurement of volume practically as accurate as by means of the volumenometer.

The porosity and volume changes in burning may also be used advantageously as a means of determining the uniformity of quality of a lot of bricks of a single brand. The behavior of such bricks should be fairly uniform if they be of equal quality. Such

application of these measurements would be of value to the manufacturer, as well as to the consumer.

A study of the curves for porosity and volume changes for a series of burning temperatures offers a means of determining, in some measure, the causes of failure of certain bricks in the load test. If this be due to underburning, resulting in excessive deformation under load due to shrinkage, a considerable decrease in porosity and volume will be found at the lower burning temperatures. Clays of inferior quality which overburn will be detected by marked expansion at some point in the burning, usually accompanied at a somewhat higher temperature by an increase in porosity due to vesicular structure. Clays lower in fluxes, and which do not readily develop vesicular structures, show gradual but marked contraction and decrease in porosity as the burning temperature is increased.

VII. SUMMARY

1. Bricks which are capable of withstanding a pressure of 40 pounds per square inch at 1350° C generally show slight changes in volume or porosity when burnt at temperatures up to 1425° C.

2. The greater number of the bricks which failed to pass the load test show rather marked change in volume or in porosity at some temperatures below 1425° C.

3. Bricks which show distinct overburning by pronounced expansion at temperatures below 1400° C invariably fail in the load test. The adoption of a definite limit for the permissible expansion within the given temperature range is particularly important for detecting inferior clay refractories. The limit of expansion should be lower than that for the allowable contraction.

4. The changes in volume and in porosity of bricks burnt at some temperature between 1350° C and 1425° C serves, in a measure, as a criterion of their ability to pass the load test.

5. Most of the bricks which show a porosity decrease not exceeding 5 per cent and a volume change not exceeding 3 per cent (approximately 1 per cent in linear dimensions), when burnt at 1400° C, will pass the load test.

6. Bricks which show a decrease in porosity exceeding 5 per cent, or an expansion or contraction in excess of 3 per cent by volume (1 per cent in length) at 1400° C, in nearly all cases failed to pass the load test.

7. The use of limiting porosity and volume changes for clay fire bricks burnt at 1400° C would serve as a means of eliminating

from consideration a large number of bricks which fail in the load test.

8. Bricks which fail in the load test due to failure in the bond may not show marked changes in volume or porosity in burning, but often show very low cold crushing strength.

9. No definite relationship seems to exist between the softening point of a fire brick and its ability to withstand load at high temperatures. However, all bricks which softened below cone 28, whether siliceous or not in character, failed completely in the load test. It seems advisable, then, to specify cone 28 as the minimum softening point for any clay fire brick. It is probable that bricks containing less than 65 per cent SiO_2 should have a minimum softening point of cone 31.

10. Bricks with an initial porosity below 21,5 per cent and with an average decrease of about six points in percentage of porosity contracted about 5.5 per cent in the load test. Bricks showing an average porosity above 21.5 per cent showed a like contraction in the load test with a change of about three points in porosity percentage.

In conclusion, the writer desires to express his appreciation of the assistance rendered by D. W. Ross, in conducting the load tests of this investigation, and to thank A. V. Bleininger for valuable suggestions in carrying out the work.

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